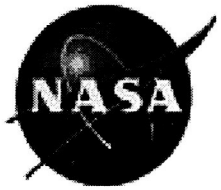
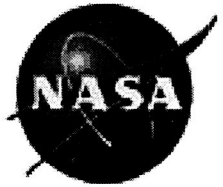


PIEZOELECTRIC SENSOR EVALUATION FOR STRUCTURAL HEALTH MONITORING OF CYROGENIC STRUCTURES

Robert Engberg
John Lassiter

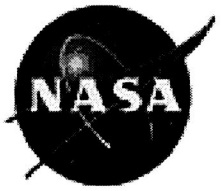
Marshall Space Flight Center
Test Laboratory

AAMU Presentation, June 2005



OUTLINE

- Definitions in Structural Health Monitoring (SHM)
- Examples of various methods/sensors for SHM
- Our work at Marshall
  - Purpose for our research: Cryogenic structures
  - Type of sensors: Piezoelectric
  - Test methodology: Impedance
  - Examples of our tests and test results

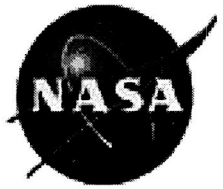


What is SHM?

- A means to detect damage in any infrastructure (aerospace, civil, etc.)
- What is damage? Changes to material and geometric properties of a structure that can affect present and future performance
  - Also includes boundary conditions and connectivity
- Examples: fatigue crack, loosening of a bolted joint
- While subjected to operational loads, damage propagates
  - Causes component level failure
  - Continuous loading causes more component failures, leading to system failures

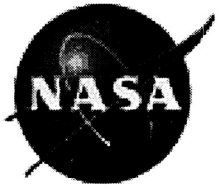
SHM Process

- Involves observation of a system over time using periodically sampled measurements using an array of sensors
- Determine features of measurements that indicate the presence of damage
- Use statistical analyses to determine state of system health



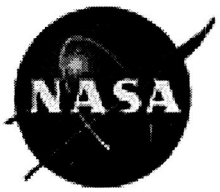
So why conduct SHM?

- Long term is needed to verify a structure's ability (integrity) to perform as designed without failure:
  - Over any given length of time
  - Subjected to any given state of operational environment which is the actual cyclic loads placed on the structure
  - Example: Determine an aircraft's usage and remaining fatigue life
- Verify the integrity after some extreme event (i.e. earthquake, blast loading, impact, etc.)
- Goal is to provide an economic and life-safety advantage
  - From time based (called hard time replacement in RCM) to condition based maintenance
  - Accurate assessment of readiness for usage and operation



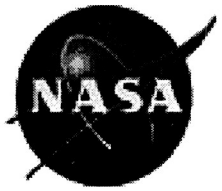
Sensors used in SHM

- Traditional sensors used in the experimental validation of the design of a structure are not considered in SHM
  - Foil type strain gages and displacement sensors are typically used to for static loads and fatigue tests
  - Accelerometers are typically used in dynamic (modal) tests
- Too many of these types of sensors are needed to detect small levels of wide spread changes in the strength and stiffness of a structure
- Other sensor technologies being researched
  - Fiber optic
  - Lamb wave propagation using piezoelectric devices
  - Impedance method using piezoelectric devices



What is piezoelectricity?

- Certain crystalline minerals call piezoceramics, when subjected to a mechanical force, become polarized
  - Tension and compression generate voltages of opposite polarity and proportional to the level of force
  - Comes from the Greek word piezein: to press or squeeze
- The converse is true: crystals exposed to an electric field lengthen or shorten in proportion to the field strength and polarity
- Piezoceramic: Mass of perovskite crystals having a tetravalent metal ion (titanium or zirconium) in a lattice of metal ions, usually lead or barium
  - Most widely used is PZT: lead zirconate titanate



Impedance based SHM

- Piezoceramic (PZT) patches couple the electrical impedance of the patch and the mechanical impedance of the structure
  - Mechanical impedance depends on mass, stiffness, and damping
- Any change in a structure's mass, stiffness, and damping due to damage will change its structural impedance, this in turn changes the electrical impedance of the patch since they are coupled
- Impedance measurements are complex (real and imaginary components) and are dependent on frequency
  - Typically high frequencies, > 30 kHz and low voltage (1 volt) to drive the patch

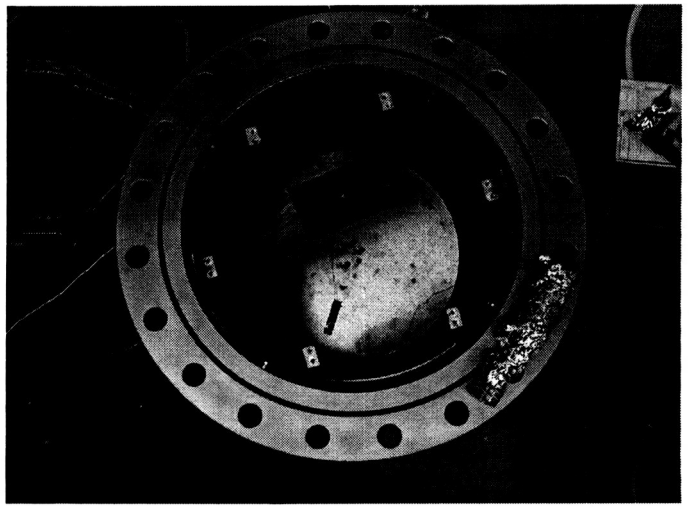
Tests at Marshall

- Work at Marshall centered on application of the impedance method of SHM for cryogenic structures
  - Cryogenic: Super cold!!!!!! Temperatures 100's of degrees below zero.
  - Cyrogenic structures: primarily fuel tanks holding liquid oxygen (LOX) and liquid hydrogen

- Tests conducted to determine how the performance of the PZT patches are affected by cryogenic temperatures
  - Identify and remove the effects of these temperatures (and pressures)
  - Only changes in the impedance is due to damage in a structure

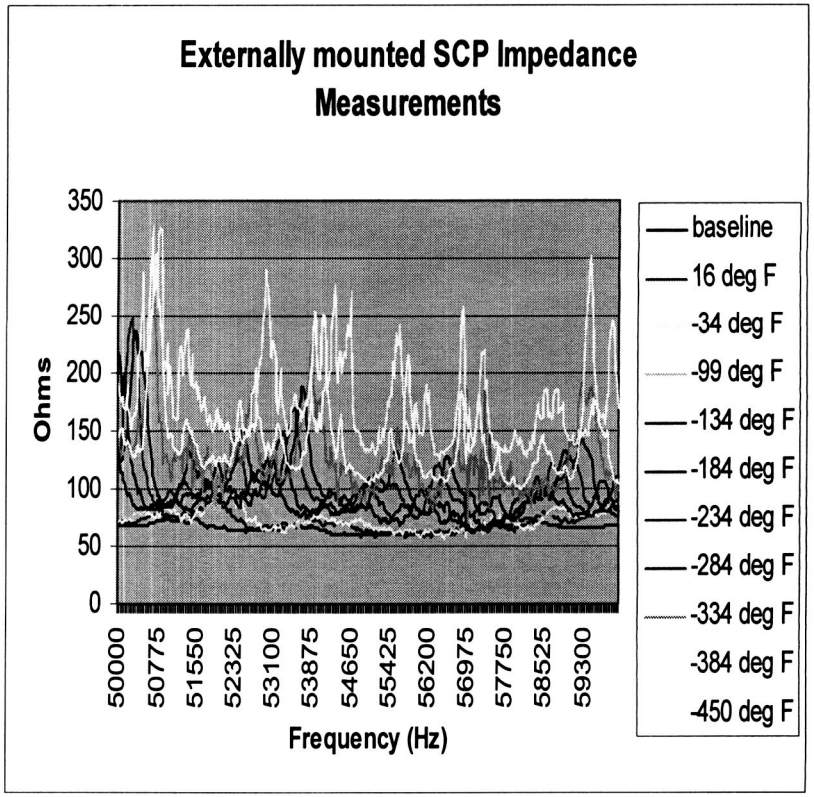
Tests at Marshall

- Two types of piezoceramic patches used:
  - PZT
  - Single crystal piezo (PMN-PT)
- First tests conducted Sep. '03
  - Patches attached to small composite plates
  - Placed in a small thermo chamber
  - 70 F to around –400 F, in 50 F increments



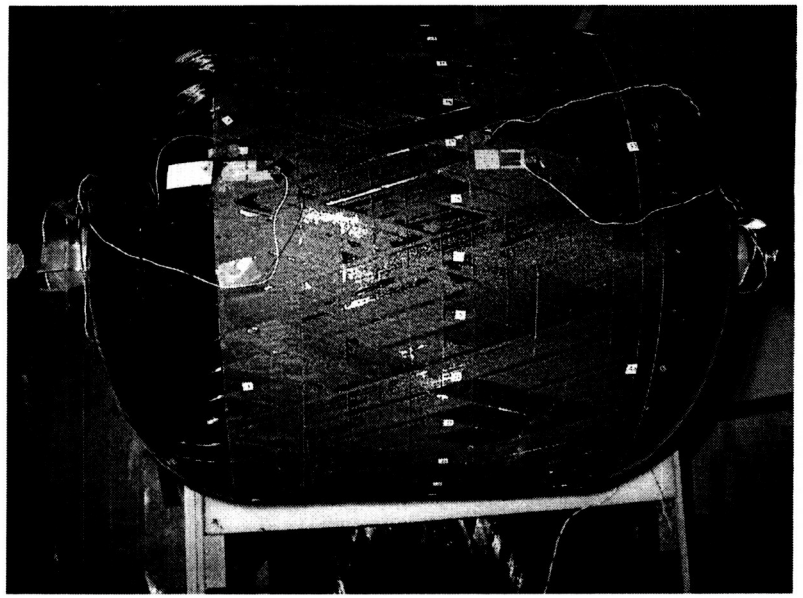
Tests at Marshall

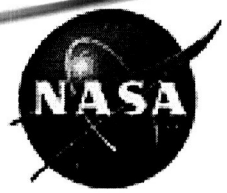
- Measured impedance for various bandwidths (i.e., 5-10 kHz) for each temperature
- Observed changes in impedance with temperature
- Identify a statistical approach to characterize changes
- Answer questions such as: Does temperature have the same affects for each bandwidth



Tests at Marshall

- Second tests conducted Oct '03
  - Piezoceramic patches attached to composite over-wrapped pressure vessels (COPV)
  - Filled with water, ambient and various pressures
  - Measured impedance at various bandwidths for each pressure
  - Also conducted modal tests for each test configuration
  - Future plans include LN2





Tests at Marshall

- Third set of tests in progress
  - Similar to second set of tests
  - New plans will include impedance measurements of PZT patches in the free-free condition, not attached to any substrate
  - Determine the changes in impedance to the presence of a substrate
  - Imaginary as well as real component of impedance will be studied, previous tests only used the real component
- Results of tests may be used for future NASA SHM requirements
  - Man-rate an expendable launch vehicle for the CEV
  - Conduct SHM on extraterrestrial habitats for Moon and Mars exploration

Reference and web sites

- Most of the material in this presentation came from the SHM short course taught by Los Alamos Dynamics Structural Dynamics Consultants
  - www.la-dynamics.com
- Web sites of piezoceramic manufacturers
  - American Piezo Ceramics, Inc.; www.americanpiezo.com
  - TRS Ceramics, Inc.; www.trsceramics.com
  - Piezo Systems, Inc.; www.piezo.com